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Chapter 9

NEUTRON ACTIVATION ANALYSIS

I. INTRODUCTION

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Definitions of Common Terms.

II. THE NAA TECHNIQUE

Neutron Activation Analysis in Criminal Cases.
Principles of Neutron Activation Analysis.
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Specific Applications.
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FROM
SCIENTIFIC
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CRIMINAL CASES

ANDRE. A. MOENSSENS
E. MOSES
F. INBAU

(FOUNDATION PRESS.
1973)

I. INTRODUCTION

§ 9.01 Scope of the Chapter

In recent years, scientists in specialized laboratories have been utilizing a method for the analysis of small particles which utilizes nuclear age instrumentation and techniques. The method is called "neutron activation analysis" and is commonly referred to as NAA. It is a nuclear, as opposed to a chemical or spectrographic method of quantitatively analyzing samples for the elements they contain.

Extensive research in NAA was done in the early 1960s at the Activation Analysis Department of Gulf General Atomic in
Diego and at Oak Ridge National Laboratory. Many of the
sary preliminary discoveries, however, date back from the
of the atom" in the 1930s and the pioneer work of Sir James
wick, Frederick and Irene Curie-Joliot, Fermi, and others.
the first activation analysis was carried out as early as 1936
Hevesy and H. Levi, progress was slow until the post World
period when the necessary research instrumentation became
able.

In this chapter, the lawyer is given a basic understanding
nature of NAA as well as its potentialities.

§ 9.02 Definition of Common Terms

Atom: The smallest particle of any element capable of existing
dependently, yet retaining the qualities that mark it as a
element.

Atomic Number: The number of protons in the nucleus of an
The number of protons in the nucleus is generally equal
number of electrons revolving around the nucleus.

Atomic Weight: The total of the weights of the protons and
in the nucleus of the atom.

Attraction: An electric attraction generated from the nucleus
causes electrons to revolve around the nucleus of the atom.

Decay: The change from an unstable to a stable atomic form
occurs when an atom absorbs neutrons. In the decay process
atom emits subatomic particles—gamma rays, protons,
particles and neutrons.

Electron: Particle possessing a negative charge equal to the
charge of the proton.

Elements, Difference Between: The difference between any
elements lies in the number of protons in the nucleus of each
This number is expressed as the atomic number.

Gamma Rays: Rays emitted by radioisotopes. Gamma rays,
by specific radioisotopes, have characteristic energy levels
can be measured to identify the source elements.

Half Life: The half life of a radioisotope is the time it takes
half of the radioactive atoms in a given sample to decay.

Isotope: A form of an element having the same number of
in its nucleus but a different number of neutrons. The
form of an isotope does not decay.

Neutron: Subatomic particle, found in the nucleus of an atom,
possesses no electrical charge and has the same
mass as a proton.

Nucleus of Atom: The center of an atom around which electrons revolve at tremendous speed. The nucleus is composed of protons and neutrons.

Protons: Particles possessing a positive charge of electricity in the nucleus of an atom.

Reactor, Nuclear: Any one of several devices in which a chain reaction is initiated and controlled with the result that heat, neutrons, and fission products are produced. In NAA, the instrument is a research-type reactor, as opposed to a power reactor for the generation of electricity.

II. THE NAA TECHNIQUE

9.03 Neutron Activation Analysis in Criminal Cases

The NAA technique for the identification and comparison of
ical evidence has wide application and potential usefulness in the
ensic sciences primarily because it provides a highly sensitive,
destructive method for the analysis of innumerable types of
nute particles of physical evidence. The federal government has
de use of NAA as evidence in criminal trials since 1964, in such
ried types of cases as those involving the examination of soils, auto-
ile putty, adhesive tape, paints, organic and inorganic particles,
ease, bullets, gun metal, galvanized wire, pipe joint compound, safe
lation, moonshine, gunshot residues, wheat paste, rope, heroin,
rijuana, etc. Because of the requirement of special facilities and
ily skilled technicians to operate the expensive equipment, NAA
s not been used routinely by state or local law enforcement agen-
ies.

It must be emphasized that NAA, though an extremely sensitive
thod of analysis, is not a panacea. It is not useful in the investi-
ation of all cases involving physical evidence. Among the other
thods of elemental analysis that are available at specialized lab-
atories are electron microprobe spectroscopy, wet chemistry, emis-
n spectrography, x-ray fluorescence, and spark-source mass spec-
metry. Of these, emission spectrography and x-ray fluorescence
e experienced wide use in crime laboratories.

§ 9.04 Principles of Neutron Activation Analysis

In any given element, each atom of the stable isotope has a defi-
ite number of protons and neutrons. For example, in carbon, there
are six protons and six neutrons. In oxygen, there are eight protons

and eight neutrons. Carbon is therefore called "carbon-12" and is designated chemically as $_6C^{12}$ or C^{12}; oxygen is called "oxygen-16" and designated $_8O^{16}$ or O^{16}. The subscript is the "atomic number", and the superscript is the "mass number."

There exists in nature a "stable" band of elements, those isotopes which have a balanced number of protons and neutrons. Isotopes which have a relatively greater or lesser number of neutrons are unstable, or radioactive. These radioactive nuclei tend to undergo some type of nuclear reaction to return to a stable form. Since radioactivity is dependent upon the proton-to-neutron balance, the part of the atom which is unstable is the nucleus. A normally stable nucleus, however, can be made unstable. This process may occur naturally, such as when nitrogen ($_7N^{14}$) atoms in the atmosphere are bombarded by cosmic rays from the sun and are transformed from nitrogen-14 to carbon-14 ($_6C^{14}$). Since an imbalance exists in these carbon isotopes between the protons and the neutrons, they are radioactive and will decay from carbon-14 to the stable form of carbon-12 with the emission of gamma rays.

Stable isotopes may be made unstable artificially; an imbalance can be induced in a laboratory by bombarding an element with neutrons so that the nucleus of the elements captures some additional neutrons as a result of which it becomes unstable; radioactive.

Neutron Activation Analysis (NAA) is a method of determining the qualitative and quantitative elemental composition of a substance by bombarding that substance, for a controlled period of time, with an intense stream of nuclear particles, usually neutrons, produced by a research-type nuclear reactor. This bombardment ("neutron activation") produces radioactive species (radionuclides) of almost all of the elements that are present in the sample.

As explained earlier, the radioactive isotopes tend to return to a stable (non-radioactive) form. This process is called the decay, and the disintegration of the radioactive elements is accompanied with the emission of high-energy electromagnetic radiations called gamma rays. The gamma rays are then counted ("analysed"), a process which reveals the half-lives of the radioactive nuclei and also their gamma ray energies. By comparison of the data then obtained with theoretical equations and experimental parameters, or by comparison with the data obtained from activating pure samples of the elements, the quantity of each element present in the substance can be determined.[1] (See Figure 56.)

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[1] Guinn, "Neutron Activation Analysis and its Forensic Applications," *Proc. 1st Int'l Conf. on Forensic Activation Analysis*, 1966.

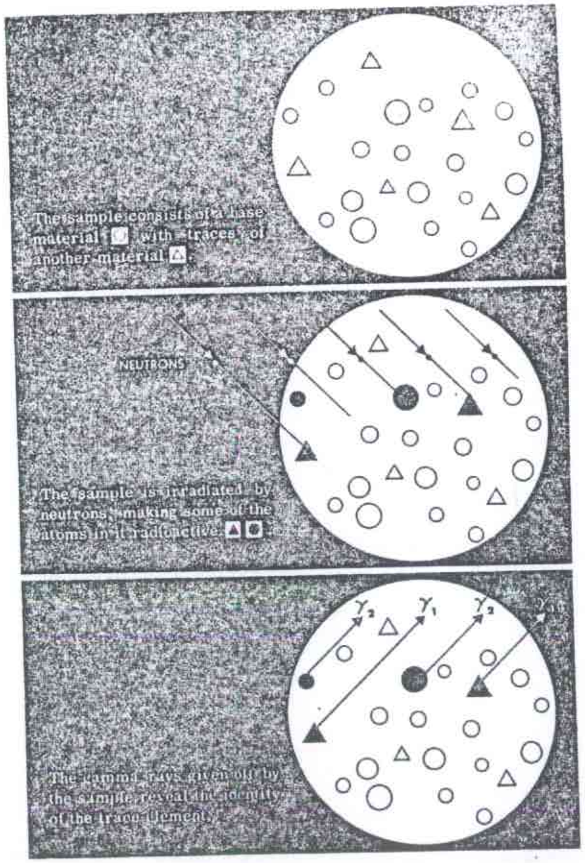
The sample consists of a base material ○ with traces of another material △.
NEUTRONS
The sample is irradiated by neutrons, making some of the atoms in it radioactive ▲ ●.
γ_2
γ_1
γ_2
The gamma rays given off by the sample reveal the identity of the trace element.

Fig. 56. In activation analysis, traces of various elements can be identified and measured by analyzing the gamma rays they give off their being irradiated with neutrons or other nuclear particles. *Courtesy: U. S. Atomic Energy Commission.*

When a radioactive element decays with the emission of gamma rays, the energy level generated differs depending upon the binding energy of the nucleus. Each isotope has one or more distinct binding energies, and therefore a characteristic gamma ray energy level. The energy of the gamma ray is designated in Mev, for "Million electron volts." The ability of a nucleus of an atom to capture bombarding neutrons also varies for each element. Generally, elements with a heavier nucleus, that is, a greater number of protons and neutrons, are more able to capture bombarding neutrons, although there are exceptions to that rule. The probability that a stable nucleus will capture thermal neutrons is measured by its "cross section" and is expressed in "barns." Some elements have low "barn" values, meaning that they capture thermal neutrons very reluctantly. An example of that is oxygen, which has a barn value of 0.0002, which makes it virtually unusable for NAA. Cross sections of stable isotopes range from about 10^{-5} all the way up to 10^{5} barns. The higher the barn value, the more sensitively the element can be detected. These three values, decay rate in half lives, decay energy in Mev, and capture rate in barns, form the basis of NAA.[2]

The instrument used in NAA is a nuclear reactor which generates radioisotopes from table specimen compounds. The reactor is fueled with a core of enriched uranium-235, which is the source of the neutrons used to bombard a suspect sample. The central core of the reactor is immersed in heavy water surrounded by a steel and lead thermal shield. The heavy water serves three purposes: (1) it slows down fast-moving neutrons which are released when the nucleus of a uranium-235 atom splits ("fissions"); (2) it removes heat created by the "chain reaction" as one after another of the uranium-235 atoms fission; and (3) it acts as a shield to protect personnel from the harmful effects of neutrons and gamma rays. The intensity of the chain reaction within the reactor can be controlled by instrumentation.

NAA techniques employ a high thermal-neutron flux produced in a research-type nuclear reactor. High-flux NAA provides much greater sensitivity than the much lower thermal-neutron fluxes available with smaller neutron generators.

§ 9.05 Description of the NAA Technique

Two different NAA techniques must be considered: the purely instrumental (non-destructive) and the radiochemical-separation (destructive) methods. In instrumental analysis, the elemental constituents of a sample are determined without physical destruction of the sample. If, however, there is an interfering substance present, a radiochemical method must be employed to remove it, with the consequence that although analytical results can be obtained, the specimen is consumed in the process. In criminal investigation, the non-destructive method is preferred.

As is the case with all trace evidence, the unknown material, whether of biological or non-biological origin, and the matter with which it is to be compared must be gathered and transmitted to the appropriate testing place. There, after washing or other removal of contaminants, the samples, along with control items to detect whether processing has added any impurities, are placed in vials. These vials are then introduced into the reactor by means of a pneumatically operated "rabbit tube" and are placed on a rotary "lazy susan" rack inside the reactor. The rotary rack is used so that the neutron flux density—that is, the number of bombarding neutrons per square centimeter per second—is the same for all of the sample.

When the reaction process is started, the elements contained in the samples are made into radioactive isotopes as additional neutrons are added to the nucleus of each of the atoms composing the substance. Atomically, the element is unchanged; that is, it has the same number of protons and electrons. It is the addition of the neutrons to its structure that makes it radioactive and causes it to emit gamma rays. After an appropriate time in the reactor, the samples are removed. The time period of irradiation varies from one to several hours, depending on the difference in barn values of the elements to be identified.

After the removal from the reactor, the samples are "counted." This is done by exposing the sample to a scintillation crystal. The unique properties of this crystal cause it to give off a flash of light when it is struck by a gamma ray. The intensity of the flash is in proportion to the energy of the gamma ray. Since each isotope emits gamma rays of distinct energy levels, the brightness of the flash of light shows the presence of certain elements. (See Figure 57.)

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[2] Ruch, *et al.*, "Neutron Activation Analysis in Scientific Crime Detection—Some Recent Developments," 9 *J. For.Sci.* 119 (1964).

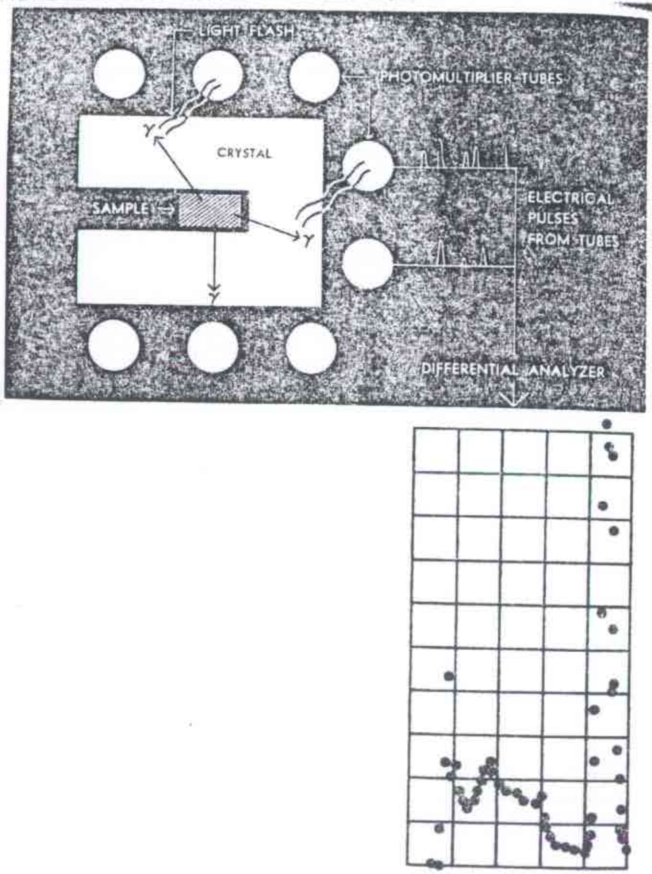

Fig. 57. Diagram of how an activated sample is counted. The lower portion of the diagram represents a pictorial image of what is seen on the screen of the oscilloscope. *Courtesy: Gulf General Atomic, San Diego, Cal.*

THE FLASHES OF LIGHT ARE DETECTED BY PHOTOMULTIPLIER TUBES WHICH convert the light energy into electrical pulses in proportion to the brightness of the flash. These electrical pulses are then fed into a multichannel differential analyzer, which then counts the number of flashes of light for each energy level or "channel." These results are then plotted graphically on an oscilloscope, or stored on tape for later display. Identification of the elements in a sample is made by comparing the graphic chart depicting the disintegration (decay) of the radioactive atom of an unknown substance with a similar chart of a known substance, identification is made possible.

Approximately seventy-five different elements can be detected by NAA. The extreme sensitivity of NAA allows it to identify some elements in concentrations as low as one-ten millionth of a microgram. Other elements, less sensitive to detection, must be present in concentrations as high as 5 micrograms (5 millionths of a gram).

§ 9.06 Specific Applications

1. GUNSHOT RESIDUE TESTS

Gulf General Atomic has developed a method to detect gunshot residues on the gunhand of a person who has recently fired a revolver or automatic pistol or even, in some instances, rifles and shotguns. The NAA test is far more accurate than the ordinary diphenylamine ("paraffin") test discussed in Chapter 4 and more reliable than the Harrison-Gilroy test as well. The method involves removal of any possible gunshot residues from a selected area on the back of the suspect's hand by a modified paraffin procedure, using a thin layer of selected paraffin and no gauze. The paraffin lift is then activated in the nuclear reactor which produces a radiochemical separation of any radioactive barium and antimony (blowbacks from the cartridge primer) thus produced. A quantitative measurement of the amounts of these two now radioactive elements, by the appropriate counting methods, completes the process. The amounts of these two elements are present in the primers used in U. S. and many foreign made ammunitions, and which are deposited in even a single firing, are normally much larger than the bare traces of the elements that may be present on the hands of persons who have not recently fired a gun.

Because of the high cost of the equipment involved, it is unlikely that all but a few law enforcement agencies will be able to acquire the necessary installation. As a result, Gulf General Atomic instituted, in 1968, a forensic activation analysis service on a nonprofit basis for the assistance of law enforcement agencies. At that time, the cost of the services was publicized as follows:

1. Nondestructive comparison of two evidence samples (such as paint, glass, metal, plastic, rubber, paper, grease, rope, tape, soil,

marijuana, etc., but excluding hair: $160. Additional samples of the same type, intercompared at the same time: $30 per sample.

2. Nondestructive comparison of two strands (or samples) of hair: $250. Additional hair samples to be intercompared at the same time: $50 per sample.

3. Analysis of one gunshot-paraffin lift: $190. Additional paraffin-lift samples analyzed at the same time: $40 per sample. Special paraffin removal kits requiring a standard procedure developed by the company are furnished and must be used.

When necessary, the radiochemist who has performed the tests will be available to testify as an expert witness at cost.

It must be noted that when the hand of a person suspected of firing a gun is heavily contaminated by perspiration, it may be impossible to detect the presence of the elements barium and antimony, by the purely instrumental method. The sodium and chlorine content of perspiration, which emits high activity levels, may obscure the traces of barium and antimony. In that type of a case, only the radio-chemical-separation form of NAA can be used, a method which permits the technician to separate the various elements but which results in the destruction of the specimen. That method is also more time consuming and requires greater skill.[3]

2. HAIR

In addition to the methods of hair comparison discussed in Chapter 8 (§ 8.09), extensive experimentation has been conducted with instrumental analysis of hair samples. The presence of some 29 minor and trace elements in hair samples has been discovered by instrumental NAA. In a typical specimen of hair of ordinary size (0.1 to 1 mg.), anywhere from six to twelve trace elements can be detected. It must be noted, however, that, depending on the degree of irradiation, the hair specimens may be damaged by radiation burns.

A. D. Perkons, who wrote a Ph.D. thesis on "Hair Individualization Study by Neutron Activation" at the University of Toronto in 1965, feels that the possibility that two hair specimens compared come from the same person requires that they agree quantitatively in the levels of all elements observed in the gamma-ray spectra, and for at least six to ten elements.[4]

One of the problems to be considered in the analysis of hair is contamination. Several trace elements discovered in hair may come from perspiration or other external sources. It may be difficult to cleanse or wash hair samples to remove dust, grease, shampoo, dye, sweat, etc. by standard washing procedures. Excessive washing in turn may remove some elements that were probably internally deposited and bound in the hair.

Another problem may be the scarcity of the sample. Frequently, one, or a few strands of hair is all that is available. The smaller the sample, the fewer chances of discovering a sufficient number of trace elements. Without a showing of strong independent evidence that multiple strands come all from one person, as where a number of hairs were found clutched in the hand of a victim, the various hairs should not be combined and treated as a single sample, but should be analysed individually, even though microscopically they appear to be quite similar. Obviously, microscopic examination of hair samples should precede NAA, because irradiation may alter the appearance of the specimens to a considerable extent. On the other hand, however, if microscopic examinations are conducted, the mounting medium used should be pure water or a pure hydrocarbon, since many of the ordinary types of mounting media have been found to contaminate the hair sample to a considerable extent.

3. PAINT

NAA has been used to examine many types, colors, brands, and compositions of paint. A total of 21 different elements have been accurately measured, though not all are found in any one paint sample.

In order to determine whether a sample of paint could be distinguished from paint samples of the same make and color but from a different can, scientists took eight different cans of paint of a same color number and of the same manufacturer, but from eight different production batches. Two samples from each can were analysed, and the results were compared. In elemental analysis, the two samples of any one can be demonstrated to be an excellent match, proving that sample heterogeneity was not a problem. But when the results were compared with those obtained from different batches of the same type of paint, it was discovered that there was a small, though clearly noticeable, variation in composition among the different production batches. The major paint constituents, titanium and zinc, exhibited very small variations, but the difference

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[3] Bryan, *et al.*, "New Developments in the Application of Neutron Activation Analysis to Problems in Scientific Crime Detection," *Proc., 1965 Int'l Conf. on Modern Trends in Activation Analysis* [Reprint].

[4] "[I]f two hair samples match in the concentrations of 8 elements they contain, the probability that they are from the same individual is 0.99999999, or 99.999999%, or stated differently, there is only one chance in about 100,000,000 of an accidental match": Guinn, "Recent Developments in the Application of Neutron Activation Analysis Techniques to Forensic Problems," 4 *J.For.Sci.Soc.* 184, 190 (1964).

See also, Perkons & Jervis, "Trace Elements in Human Head Hair," 11 *J. For.Sci.* 50 (1966). R. E. Jervis, one of the co-authors of this work, has appeared as a defense witness in several trials. In this report he stated, at p. 62: "Activation Analysis is, however, still a long way from being a routinely employable tool in crime detection work. There are many questions to be answered 'beyond any reasonable doubt,' and any premature use of the method can only retard the eventual benefit derived from it."

WAS MUCH MORE NOTICEABLE with minor constituents and trace elements, such as indium.[5]

4. SOILS AND PLANTS

Different species of plants which are grown in the same location (same soil composition) and with the same supply of water and identical sun exposure, will still exhibit different trace-element levels because their metabolic processes vary. The same species of plant grown in a different location—in soil with a different composition, and where they may be expected to be exposed to more or less water and sunlight—will also show greater differences in trace-element levels. Therefore, if the police seize quantities of marijuana from different individuals, neutron activation analysis can establish whether the plants were grown in the same location, and thus have a common origin, or whether they were grown in different locations.

Some of the earliest applications of NAA as an evidentiary tool were in soil comparisons, to show that mud scraped from a truck carrying moonshine was the same mud as was found at the site of the still, located in a different state.[6]

5. DETERMINING FIRING DISTANCES

Neutron Activation Analysis has also been used as a technique for accurately determining firing distances in criminal cases by evaluating the concentration patterns of the metallic residue deposited around bullet holes to determine muzzle-target distance. The bullets used were made of lead alloy containing antimony. The technique involves these principal steps:

1. Test shots were fired from various distances using the weapon and the type of ammunition in question. A paper filter or cotton cloth target is used.
2. Eight concentric circles each 0.25 cm in width with the bullet hole in the center are cut from the case shot and test shot targets.
3. The samples are irradiated using a research reactor.
4. The energy levels of the gamma rays emitted by the isotopes of the antimony elements present is counted.
5. A graph of antimony concentration vs. firing distance is prepared, using the data from the test shots.
6. The firing distance is estimated by comparison of corresponding samples from case shots with those of the test shots.

THIS METHOD HAS BEEN SHOWN TO ~~[illegible]~~ GIVE SHOOTING DISTANCES WITH A deviation of +2 inches in many cases by empirical relationship between the antimony concentration around the bullet hole and the muzzle-target distance.[7]

6. MISCELLANEOUS

NAA has also been utilized to identify the type of grease used by cars involved in hit-and-run accidents. In a study of thirteen commercial chassis-lubricant samples, no two were anywhere near identical; eleven elements were found in one or more of the samples and the number of elements found in any one sample ranged from a minimum of one to a maximum of eight. These data indicate the feasibility of determining the band of grease involved in a criminal case by using radioactive analysis.

Among the other substances which have been the subject of intensive empirical research with NAA techniques are, commercial plastics, automobile tire rubber, wood samples (weighing from 5 to 29 milligrams), glass, paper and ink, narcotic samples (opium), pesticide residues in food stuffs, etc.[8]

III. EVIDENCE OF NAA TESTS

§ 9.07 Admissibility of Test Results

1. TRIAL COURTS

While only a limited number of reviewing courts have dealt with NAA test results as evidence so far, by 1969 evidence of that type had been used in over fifty criminal trials.[9]

The first case in which Neutron Activation Analysis data were introduced into evidence was a case brought by the Internal Revenue Service involving a charge of transportation of whiskey on which the required tax had not been paid. The prosecution contended the whiskey ("moonshine") had been transported to New York from an illicit still operating in Georgia. The United States introduced, as evidence, the gamma ray spectra of neutron activated soil. The results proved that soil taken from the underside of a truck seized in New York matched in elemental composition the soil sample taken from the property on which the still was located.

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[5] Bryan, *et al., op. cit., supra* n. 3.

[6] Hoffman, *et al.*, "Forensic Comparison of Soils by Neutron Activation and Atomic Absorption," 60 *J.Crim.L., C. & P.S.* 395 (1969).

[7] Krishnan, "Firing Distance Determination by Neutron Activation Analysis," 12 *J.For.Sci.* 481 (1967).

[8] Ruch, *et al., op. cit., supra* n. 2.

[9] Early trial court decisions admitting NAA evidence were listed in United States v. Stifel, 433 F.2d 431, at 440 (6th Cir. 1970), *cert. denied* 401 U.S. 994. Factual data was obtained from Bryan, *et al., op. cit. supra* n. 3; and Guinn, *op. cit. supra* n. 4.

The second case in which NAA was used was brought a few months later, May 20, 1964, in an Ohio court. The charge was attempted murder by mailing a bomb to the intended victim. The prosecution introduced into evidence the NAA proof that the materials used in making the homemade bomb came from materials found at the suspect's place of employment. Again, a conviction resulted.

The third case was decided in a California court on July 3, 1964, on a charge of attempted burglary. The state introduced into evidence radioactive analysis of chips of paint from a tire iron found in the defendant's car and the comparison with the analysis of paint from the back door of a liquor store which the defendant allegedly attempted to open. The trial resulted in a guilty verdict, probably based solely on the NAA evidence presented, as there was no other evidence to connect the defendant with the act.

In a reported trial court decision from the United States District Court in New York,[10] the court admitted NAA evidence establishing the integrity of a questioned document, but decided not to consider the test results in reaching a decision. The court said:

> "While the tests performed by Mr. C. Michael Hoffman . . . were of great interest, his conclusions, while not rejected, have not been placed in the balance in view of the credible evidence introduced by the defendants through Dr. Vincent Guinn, that the reliability of this test is open to question in the light of its relatively recent origin and the necessarily limited experience connected therewith." [11]

2. REVIEWING COURTS

The early appellate decisions dealing with NAA test results were qualifiedly enthusiastic on the issue of admissibility. In Ward v. State,[12] the prosecution had a chemist toxicologist testify to microscopic comparisons of pubic hairs. After defense counsel, while cross-examining the state's pathologist, had elicited the suggestion that "atomic reactivator" tests were perhaps more reliable than microscopic hair examinations, the state recalled the chemist-toxicologist, and he was permitted to testify that a "neutron activator" test had been run, in his presence, at the Texas A. & M. University laboratory. He was permitted to express an expert opinion from his microscopic examination, corroborated by the neutron activation test, that the two hairs taken from the victim and those taken from the appellant were "identical" and "probably" came from the same person.

In 1969, three reviewing courts dealt with NAA evidence. The first one was State v. Holt,[13] decided by the Ohio Supreme Court. Again, the evidence consisted of pubic hairs in a rape prosecution. The state's expert in this case was a nuclear chemist connected with the research laboratory of the Union Carbide Corporation. When he was asked whether he had an opinion "based on a reasonable scientific certainty as to the similarity or dissimilarity of the hair specimens," he stated that the samples were "similar" and were "likely to be" from the same source. In reversing the conviction, the Ohio Supreme Court decided that such a response did not reach the degree of certainty which the law demands, and that consequently his testimony should have been rejected. Recognizing that absolute certainty is not the required standard, the court nevertheless felt that "likely" was weaker than "reasonably certain," and concluded that since the procedures and results are still subject to challenge, NAA had not yet reached the point of generally proven reliability.

The second 1969 decision was State v. Coolidge,[14] a first degree murder conviction. A consultant in microanalysis and director of a university laboratory had testified as an expert for the state that of forty particles obtained by vacuuming the victim's clothing, twenty-seven were indistinguishable from and similar to particles obtained from the defendant.[15] His conclusion, expressed on the basis of statistical probabilities, that the probability of finding 27 similar particles in sweepings from independent sources would be only one in ten to the 27th power, was held properly admitted.

In *Coolidge*, the state also proffered testimony of NAA tests conducted upon pubic hairs found on the victim's body and clothing which had been found to correspond to specimens obtained from the defendant's pubic region. When defense counsel strenuously objected to testimony of this type, the trial court conducted a hearing on the admissibility of the evidence in the absence of the jury, at which hearing both sides presented expert testimony on the technique used and the underlying scientific principles. At the conclusion of the hearing, the trial court excluded evidence relating to hair comparisons, but admitted into evidence test results of particles vacuumed from the victim's clothing which had been compared with particles coming from the defendant's clothing and car. In so doing, the trial court recognized that while NAA test results were not being introduced as being "as infallible as fingerprints," the results were being offered to show the similarities of the particles based upon a qualitatively and a somewhat quantitative examination of the particles by Neutron Activation. In so ruling, the trial court was found to have properly applied the principle governing admissibility of novel scientific tests as enunciated in Frye v. United States.[16]

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[10] United States v. Wolfson, 297 F. Supp. 881 (D.C.N.Y.1968), *aff'd* 413 F.2d 804 (2d Cir. 1969).

[11] *Id.* at 888.

[12] 427 S.W.2d 876 (Tex.Crim.App. 1968).

[13] 17 Ohio St.2d 81, 246 N.E.2d 365 (1969). The expert stated that comparative tests of human hair had been "of far less frequent occurrence than comparative tests of other substances, such as soils, minerals and metals," and that the tests are "not conclusive."

[14] 109 N.H. 403, 260 A.2d 547 (1969), *cert. granted* 399 U.S. 926.

[15] The tests used included visual microscope observation, comparative refractive indices, solubility tests, and Hirschberg stain tests for paper particles.

According to *Frye*, in order for the results of scientific tests to be admissible, the scientific principle involved must be sufficiently established to have gained general acceptance in the particular field in which it belongs. The argument that the defendant's expert testified that he would have subjected the particles to longer periods of radiation, and would have required a more absolute qualitative testing, was said by the court to go only to the weight of the evidence, and not to its admissibility. An important facet of this case is that the court reached its decision on the admissibility of NAA evidence even though qualified defense experts had reached conclusions different from those expressed by equally qualified state experts.

The third 1969 decision was handed down by the 2d Circuit Court of Appeals in United States v. Kelly,[17] where the defense attacked NAA evidence tending to show the common origin of drug samples as scientifically unreliable. The defense presented as its expert Dr. R. E. Jervis [18] to make this point. The court held that the evidence was properly admitted, and that it was the jury's duty to decide the conflicting claims as to its reliability. However, the court reversed and remanded because the defense had not been given an opportunity to have its own expert run NAA tests so as to be able to properly evaluate the government's findings.

Late in 1970, the Sixth Circuit Court of Appeals gave unqualified approval to NAA as having met the *Frye* [19] "general acceptance" test. Recognizing the paucity of precedent and the relative novelty of the procedure, the court exhaustively explored the literature. In distinguishing the *Holt* and *Kelly* decisions, the court also made this astonishingly enlightened comment on the need to make tests of this type available to the defense:

> "While we believe that the neutron activation analysis evidence meets the test of admissibility in this case, we also note that like any other scientific evidence, this method can be subjected to abuse. In particular, if the government sees fit to use this time consuming, expensive means of fact-finding, it must both allow time for a defendant to make similar tests, and in the instance of an indigent defendant, a means to provide for payment for same. . . ."[20]

While no significant cases dealing with NAA evidence were reported during 1971,[21] the courts will probably, and properly so, accept NAA as a means of comparing small particles for the purpose of determining common origin that is worthy of judicial proof. In fact, since the principles upon which the techniques rest are so well established, and universally approved by the scientific community, it would be entirely proper, at this time, to take judicial notice of the underlying principles.

§ 9.08 Qualifications of the Expert

None of the reviewing courts to date have had an opportunity to decide whether a witness, testifying on NAA test results, was qualified to give opinion evidence as an expert. All of the experts who have testified so far have been assumed to be competent and their qualifications have not been seriously challenged. One of the reasons for this might be that defense attacks have centered, so far, on contesting the reliability of the technique itself. More likely, however, it is because the witnesses were extremely well qualified, and most of them came from outside the law enforcement field. The fact that crime laboratories quite generally do not have research reactors and are forced to appeal, in large measure, to established research laboratories, universities, and commercial establishments, probably is a good guarantee that the examiners are highly qualified, both in formal education and in experience with the technique. The nuclear reactor is simply not a piece of equipment that will be entrusted to the unqualified hands of a trainee, as may occur with a microscope in a crime laboratory.

Among the experts who have testified are, a nuclear chemist of the Union Carbide Corporation research laboratory,[22] research chemists employed by the Treasury Department, Alcohol and Tobacco Tax Division, and the technical director of the NAA department at General Atomic Division, General Dynamics Corporation.[23]

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[16] 54 App.D.C. 46, 293 Fed. 1013 (1923).

[17] 420 F.2d 26 (2d Cir. 1969).

[18] See reference to Jervis' work, *supra* § 9.06 [2] and n. 4. According to the court's opinion, Jervis did not question the reliability of NAA but attacked the procedure followed by the government's expert witness.

[19] Frye v. United States, *supra* n. 16.

[20] United States v. Stifel, 433 F.2d 431, 441 (6th Cir. 1970), *cert. denied* 401 U.S. 994. The NAA test evidence consisted of comparisons of portions of a mailing label, cardboard mailing tube, metal cap and rim, and plastic tape with similar items obtained from a known source.

[21] Neutron Activation Analysis testimony was deemed admissible in State v. Stevens, 467 S.W.2d 10 (Mo.1971).

[22] In State v. Holt, *supra* n. 13, the witness was referred to as one of "apparent prestige" and solid educational background.

[23] Both appeared in United States v. Wolfson, *supra* n. 10, the former for the government, the latter for the defense. The same government expert also testified in State v. Coolidge, *supra* n. 14. The defense expert was not identified in the court's opinion, but was probably Dr. R. E. Jervis, since the expert was referred to as the "principal worker in the field" of hair comparisons. Dr. Jervis also testified as an expert for the defense in United States v. Kelly, *supra* n. 17.

IN ONLY ONE reported case was there even a half-hearted attack on the qualifications of the expert. That was Ward v. State,[24] where the court deemed qualified a chemist-toxicologist who testified to the results of NAA tests conducted by someone else in his presence.

Since Neutron Activation Analysis is not a chemical process, expertise in chemistry and toxicology alone would certainly not qualify a witness as an expert in NAA,[25] but the opinion in *Ward* suggests that the witness was deemed qualified because he testified that "he felt that he was qualified to testify as to the results of such tests."[26]

IV. TRIAL AIDS

§ 9.09 Locating and Engaging the Expert

As its name implies, nuclear activation analysis requires the availability of a nuclear reactor, the cost of which ranges from $200,000 to $400,000, in addition to the services of a qualified atomic physicist or nuclear chemist. Obviously, even the better equipped police laboratories do not have such an instrument, at least not as yet. However, several enforcement arms of the federal government do possess or have access to such facilities; among them are the FBI, the Alcohol and Tobacco Tax Division of the Treasury Department, and the U. S. Postal Laboratory.

State prosecutors and defense attorneys, then, are pretty much on an equal footing in terms of obtaining the services of qualified experts. They have to seek assistance at specialized laboratories of industry, independent research laboratories, and universities. The only qualified laboratory that instituted a regular forensic service in NAA is Gulf General Atomic at San Diego, California; its services are available to prosecution and defense alike.[27] The National Bureau of Standards in Washington, D.C., also has a nuclear reactor at the Center for Radiation Research which is made available to governmental agencies, industry, and universities for work utilizing radiation techniques.

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[24] *Supra* n. 12.

[25] It may well be that the expert had the required qualifications, but such is not apparent from the court's opinion, and he was quoted as saying, at p. 884, that he understood the "chemical" process at work in NAA.

[26] Ward v. State, *supra* n. 12, at 884. He also testified that he could perform the test.

[27] The service was described earlier in § 9.06 [1].

V. MISCELLANEOUS

§ 9.10 Bibliography of Additional References

Books and articles cited in the footnotes to this chapter are not repeated in this section. The scientific literature on NAA has been unusually abundant. General Atomic Report GA–7989, titled "Activation Analysis Publications Prepared by the Activation Staff at General Atomic," a 27-page bibliography, provides a detailed reference of each of the 144 published papers and major reports made available since the initiation of NAA research through September 1, 1967. The yearly compilations "What's New" published by the American Academy of Forensic Sciences, and edited by one of the present authors [Moenssens], have listed in excess of one hundred publications since 1967. The National Bureau of Standards, in its Technical Note 519, published in 1970, lists a bibliography of over 100 scientific papers dealing with NAA.

A few of the more readily available publications are listed below:

"Identification of Substances by Neutron Activation Analysis," 15 *Am. Jur. Proof of Facts* 115 (1964).

Chan, "Identification of Single-Stranded Copper Wire by Nondestructive Neutron Activation Analysis," 17 *J.For. Sci.* 93 (1972).

Forslev, "Nondestructive Neutron Activation Analysis of Hair," 11 *J.For. Sci.* 217 (1966).

Guinn, "The Identification of Hair, Paper and Paint Specimens by Means of Neutron Activation Analysis," *Identification News*, Mar. 1966, p. 4.

Hoffman, "A Simplified Method of Collecting Gunshot Residue For Examination by Neutron Activation Analysis," *Identification News*, Oct. 1968, p. 7.

Krishnan & Nichol, "Identification of Bullet Holes by Neutron Activation Analysis and Autoradiography," 13 *J.For. Sci.* 519 (1968).

Krishnan, *et al.*, "Rapid Detection of Firearm Discharge Residues by Atomic Absorption and Neutron Activation Analysis," 16 *J.For. Sci.* 144 (1971).

Ruch & Guinn, "Detection of Gunpowder Residues by Neutron Activation Analysis," 29 *Nuclear Sci. & Engin.* 381 (1964).

Schmitt & Smith, "Identification of Glass by Neutron Activation Analysis," 15 *J.For. Sci.* 252 (1970).

Smith, "The Interpretation of the Arsenic Content of Human Hair," 4 *J.For. Sci. Soc.* 192 (1964).